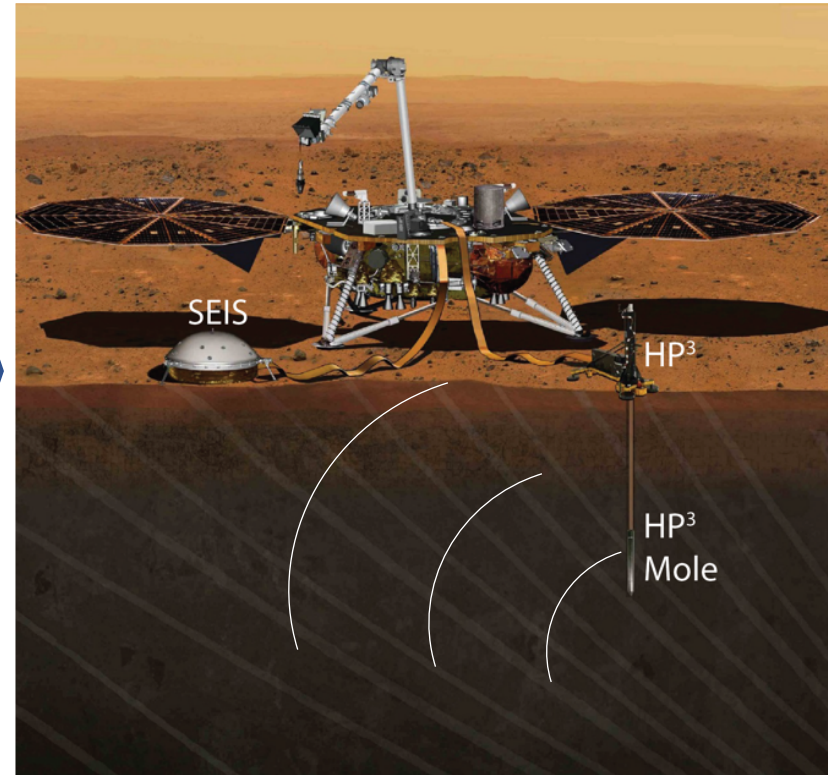
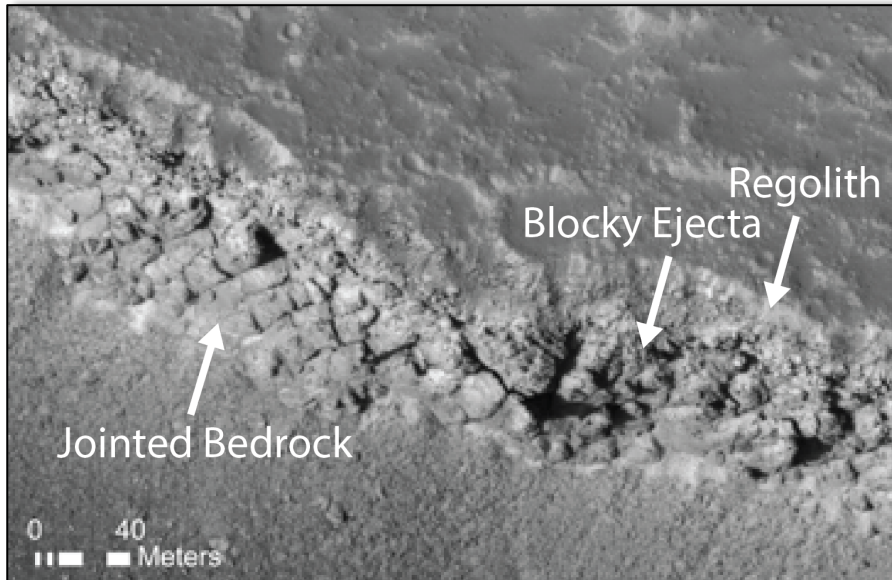


DI42A-04 - CHARACTERIZATION OF THE InSight LANDING SITE NEAR SURFACE PROPERTIES USING THE HEAT FLOW AND PHYSICAL PROPERTIES PROBE (HP³) MOLE AS A SEISMIC SOURCE



Objectives:

Use the seismic signal from the repeated HP3 mole to:

1. Obtain seismic velocity of regolith
2. Determine regolith thickness



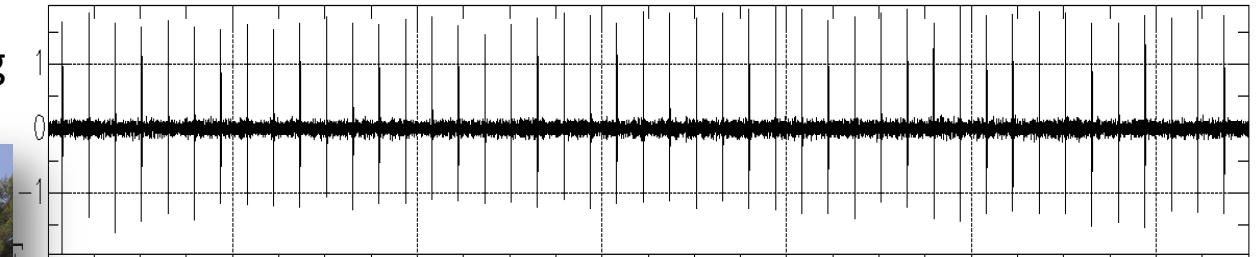
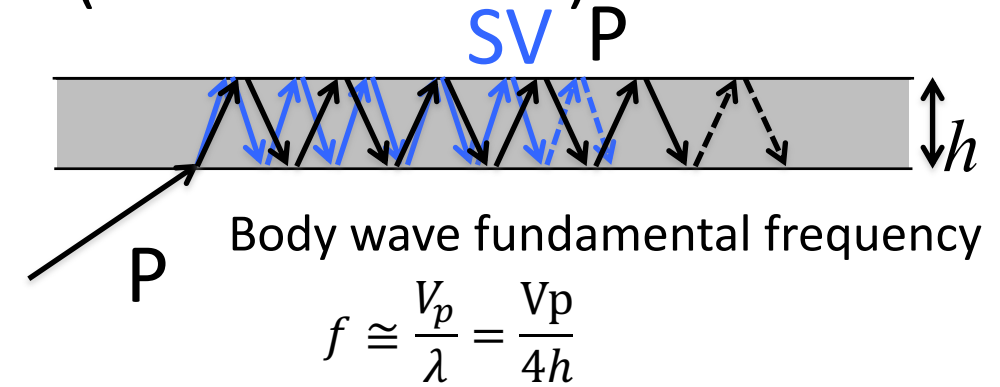
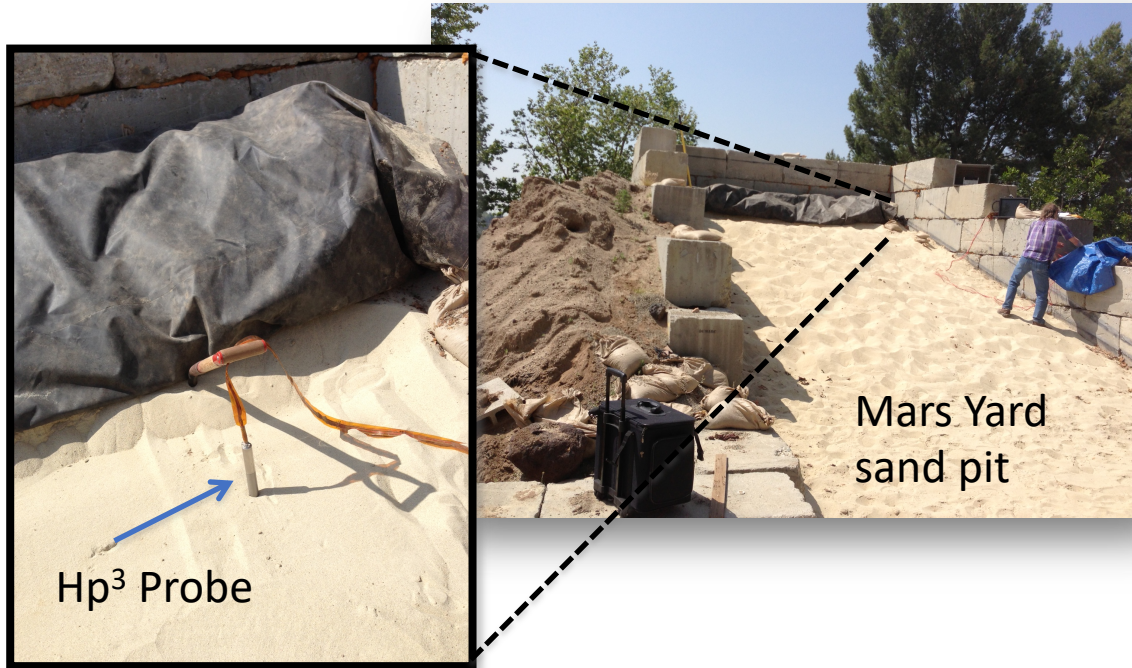
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Experiment Inception (2013-2014)

Goal: Determine the depth and elastic properties of Martian regolith at the InSight landing site.

- Martian soil properties are of interest in their own right.
- Soil properties constrain the seismic excitation by atmospheric sources.
- A soft layer over a faster hard rock is a good “trap” or waveguide for elastic waves that can potentially be excited by natural events, depending on both material and source properties
- HP³ may be turned on before SEIS is fully deployed – providing an excellent “state of health” test to SEIS during deployment.



Conclusions:

- **The HP³ source would be visible** at 3-5ft by SEIS and SP
- The **down-sampling to 100Hz by SP degrades the signal** but energy packets are still easily observable at 3ft.
- Correcting for source depth while stacking will substantially improve the accuracy of the measurement
- **Knowing the source timing to better than 1ms would be helpful**
- **A reflected signal from a 50m deep horizon is likely to be observable.**
- Stacking of the HP³ signal can potentially be used to observe a reflection from the bottom of the regolith and resolve regolith depth and potentially V_p .

Synthetic Data Set and Analysis (2015-16)

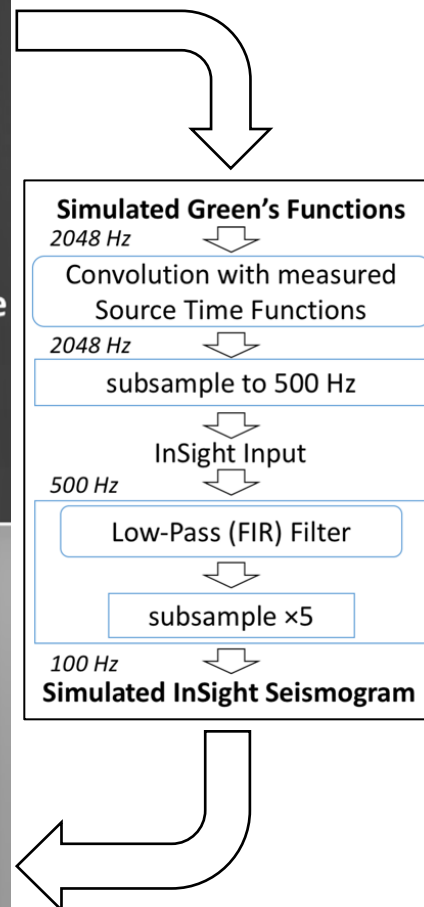
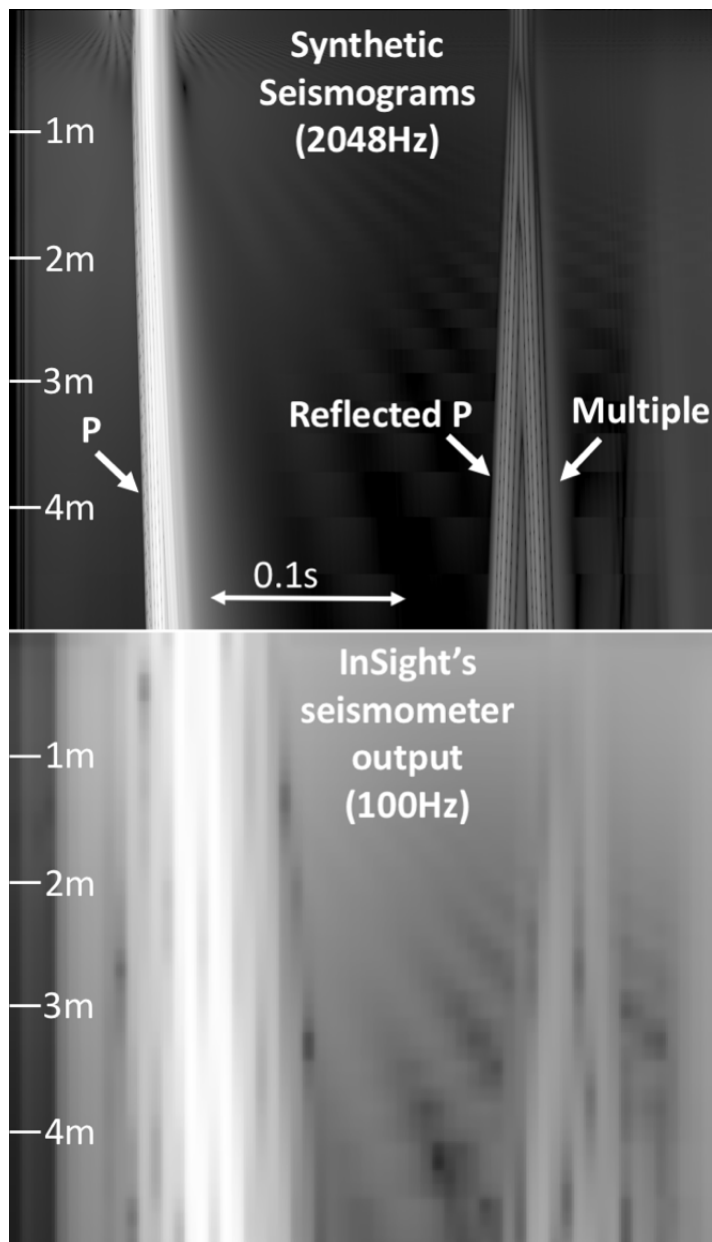
Synthetic Dataset

Model:

Thickness (m)	V_p (m/s)	V_s (m/s)	ρ (kg/m ³)	Q_p
50m	300	173	1500	50
Half-space	2000	1154	2700	100

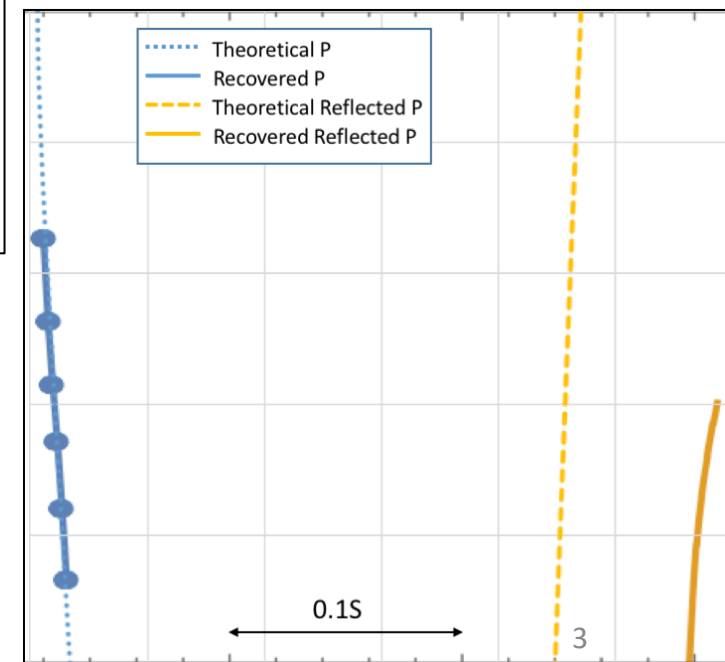
Assumptions:

- Perfect knowledge of mole depth
- Knowledge of impulse time
- 1mm downward travel per stroke



Conclusions:

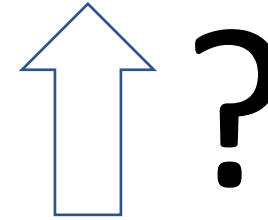
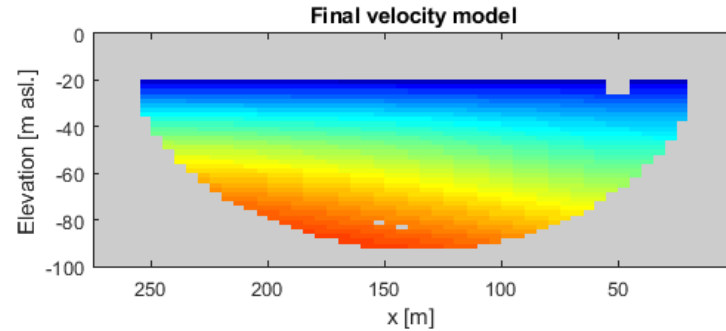
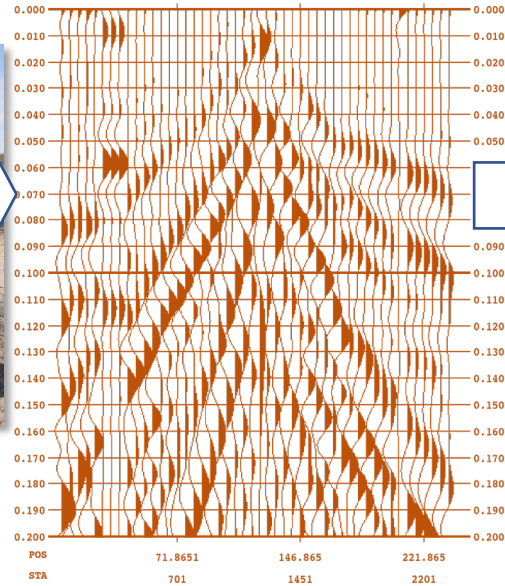
- Simulation of a soft layer over half-space incorporating InSight's seismic data sampling chain shows that the **under-sampled signal will be blurred**.
- Nevertheless, analysis combining sinc-function interpolation and tracking maximum amplitudes in consecutive time bins demonstrated here shows that the **key information regarding the shallow Martian subsurface (P-wave velocity, and regolith thickness) can be recovered**.
- **Real World Field Experiment is needed.**



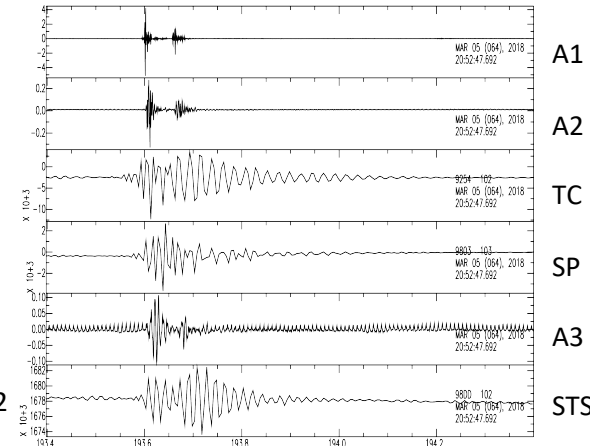
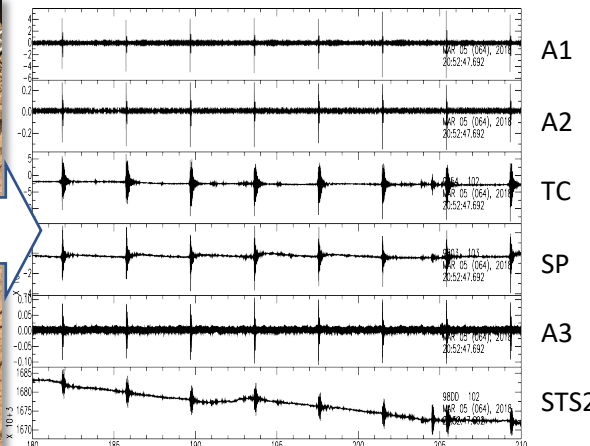
Field Experiment – Harper Hills (2017-18)

The Harper Hills area in the Mojave desert was selected since it provides a sharp contact between sedimentary and an igneous rock layer. The hills expose crystalline bedrock composed of gneiss and granitoid (fast). Unconsolidated alluvium (very slow) flanks the hills on all sides. This is a geological setting in which the ability to resolve the shallow subsurface using HP3 signals can be tested.

Phase A: Ground Truth



Phase B: HP³-SEIS Experiment



Conclusions:

- We should be able to determine the seismic velocity in the regolith from direct timing measurements using STATIL time tags and HP³ depth. i.e. it is **likely we will meet Objective 1.**
- Thickness of regolith layer (Objective 2)
 - Is **a lot more challenging than originally thought**, especially if the hard rock reflector is shallow, as the reflected signal will be hiding in the (under-sampled) fuzz of the HP³ reverberation and possibly the **time-variable 2nd stroke.**
 - Things are going to get more complex as the data is down-sampled.
- Few strategies we need to explore:
 - Understand relative timing of HP³ double strokes
 - Better characterization of the source time function through lab measurements.
 - Data processing: **Recovery of high frequency data through FIR filter optimization and post processing techniques (ETH)**
 - Deconvolution of the source time function:

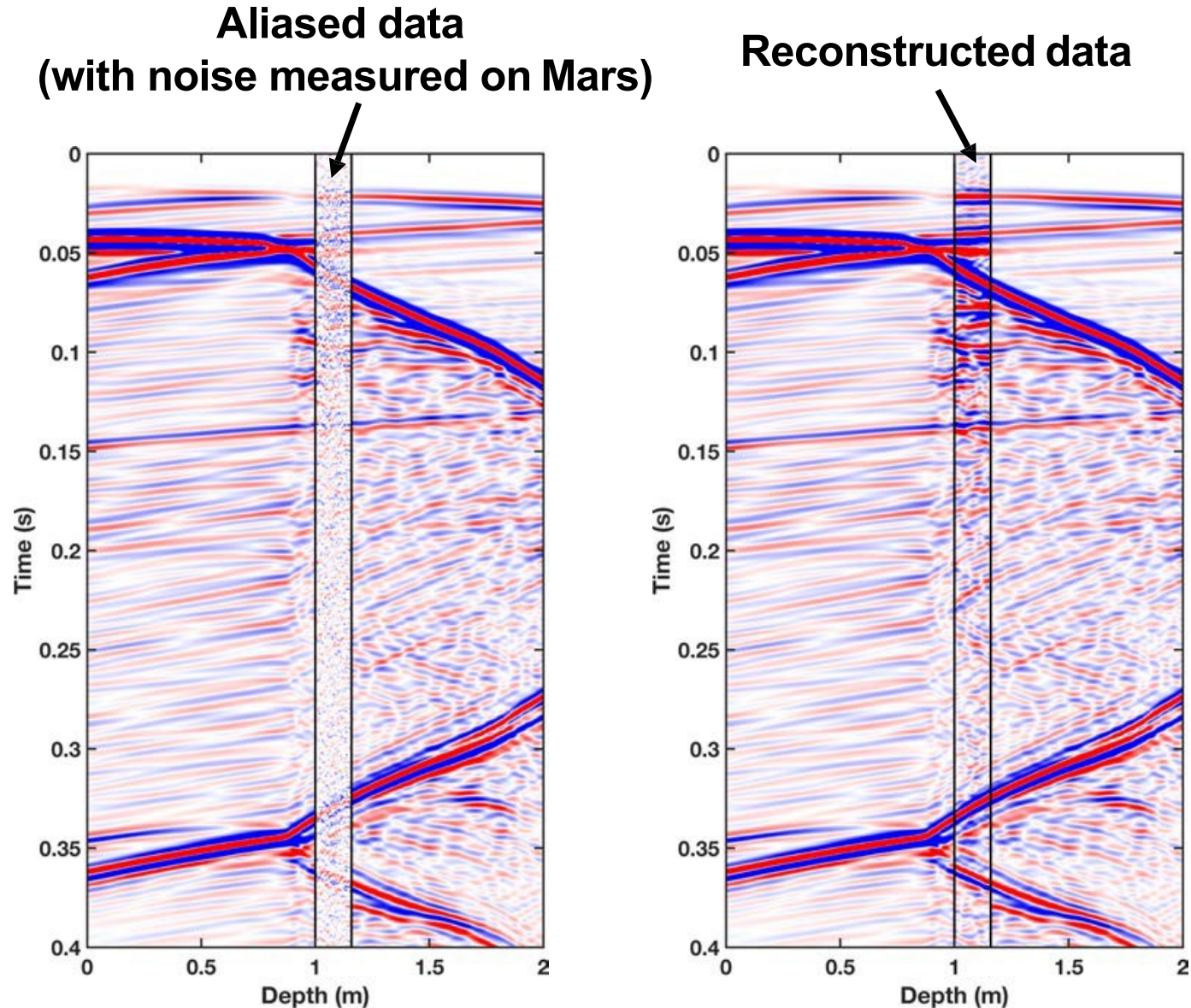
Increase resolution in time: record aliased data

Acquisition

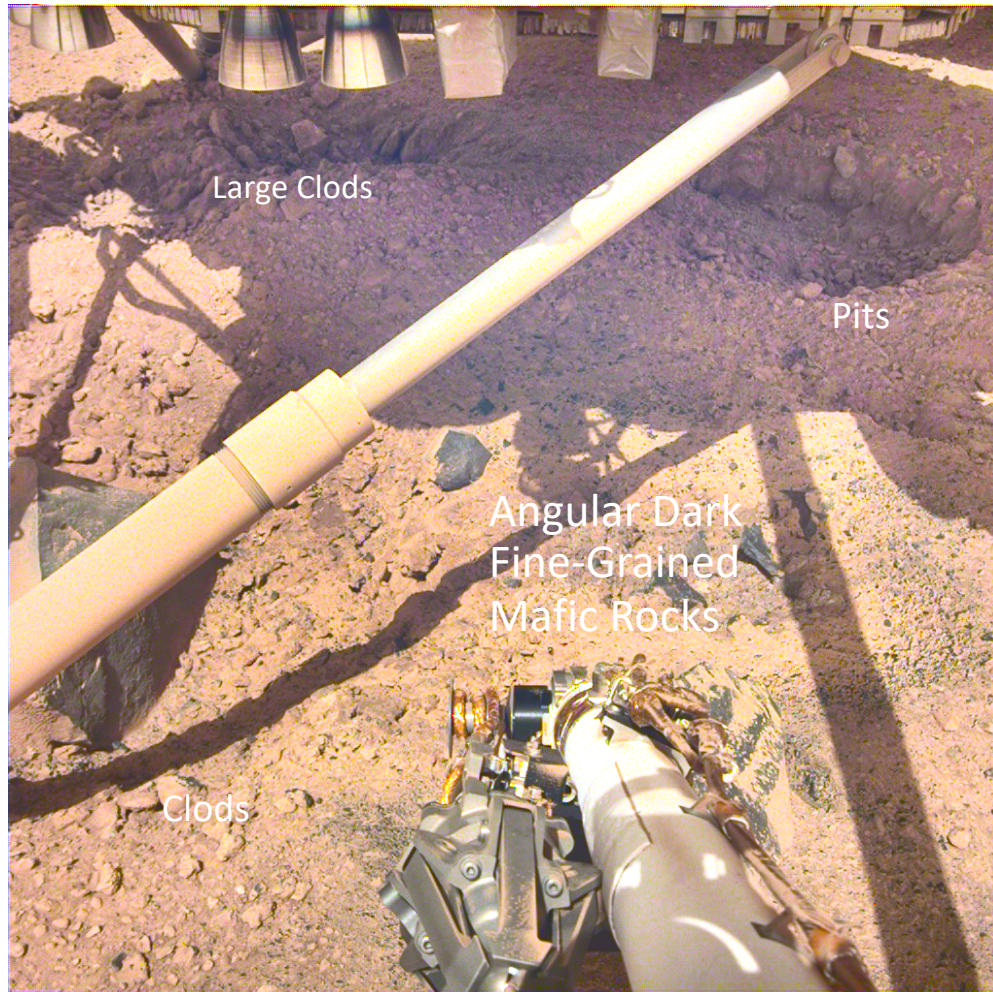
- Record aliased data (turn-off FIR filter)

Algorithm

- Use **compressive sensing** to reconstruct missing information from aliased data
- *Poster on reconstruction technique with Mars data from hammering session 3 by Sollberger et al. X4.147*



The Real Deal (2018-19)

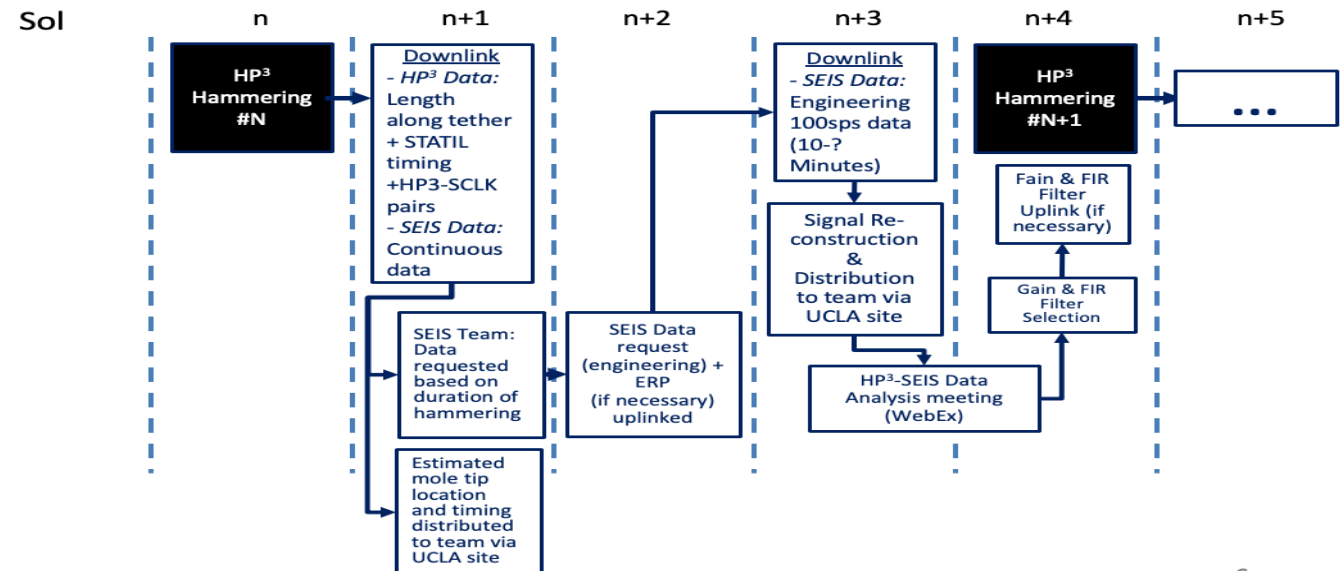
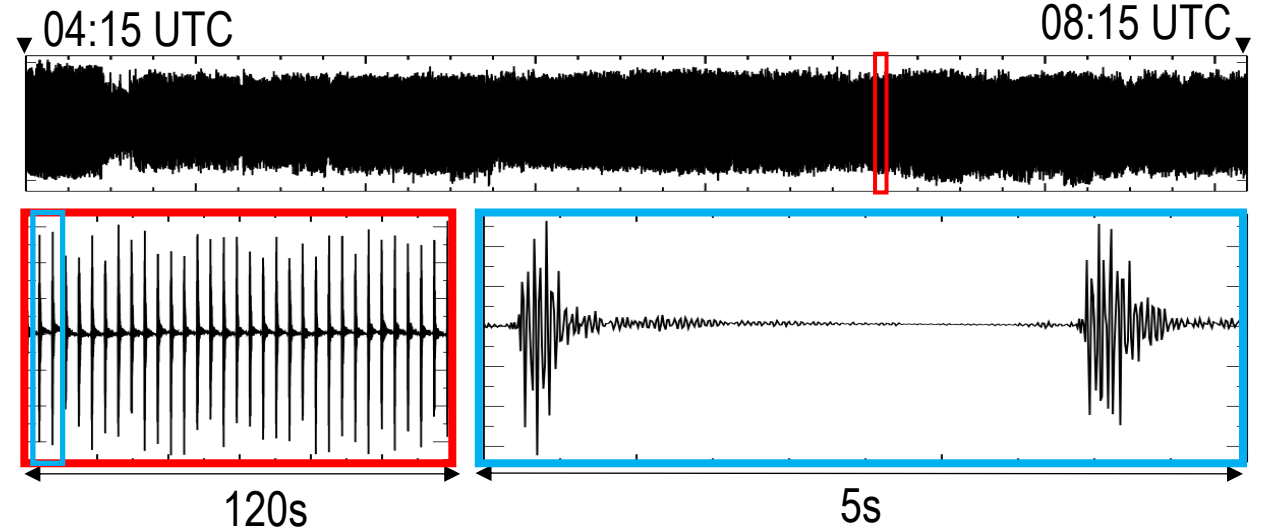


Landing site geological setting:

Pits beneath thrusters: 10-20 cm deep steep walls (\gg Angle of repos;
 Clasts within Soil Cohesion, Cemented duricrust 5-10 cm thick; Lower
 slopes beneath - cohesionless soil. Likely Similar to Other Weak Soils
 Mars <10 kPa (Golombek et al. 2008)

Assessment from Geology WG - ~3m of regolith over basalt.

HP³ Hammering was recorded with high SNR on SEIS (Session 1, March 1, 2019)



SEIS Tracking of the HP³ Mole

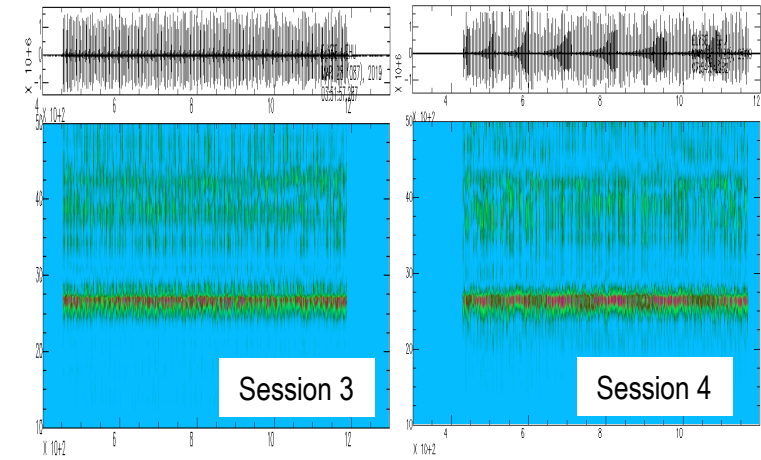
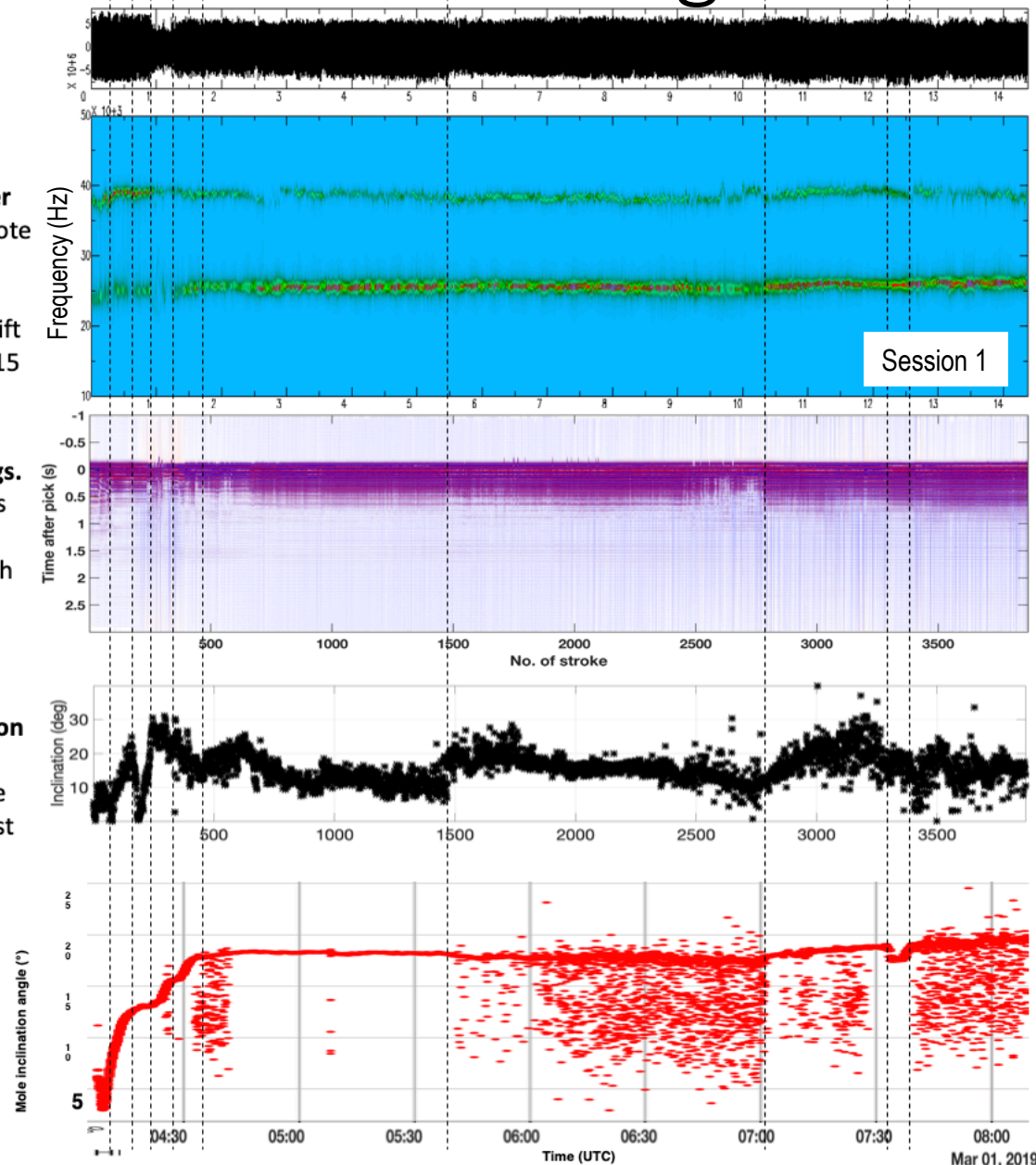
A: 4-hour long seismic recording of the first hammering recorded on the vertical SP seismometer.

B: Four hours SEIS recording of first hammer session (100 sps data). Note intervals with distinct amplitude patterns. Spectrogram indicates shift in dominant frequency ~15 minutes into mole hammering.

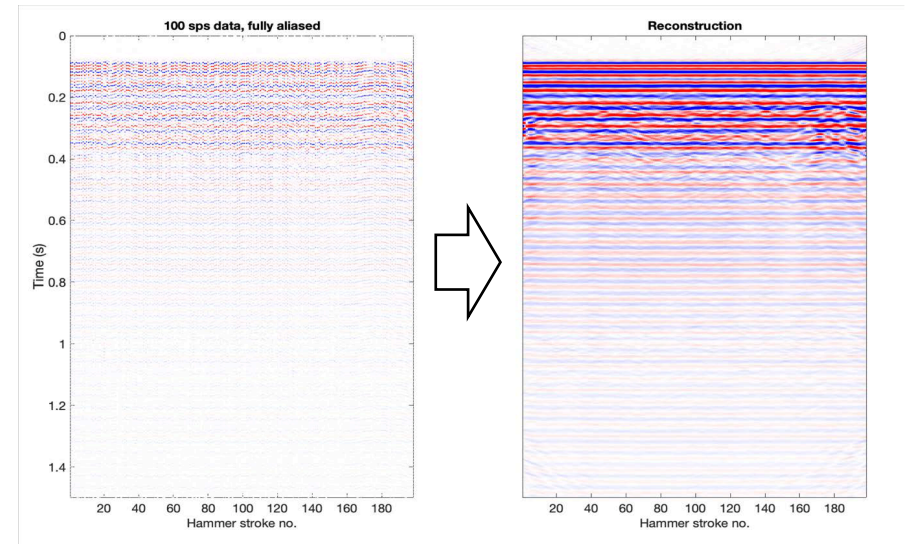
C: Re-arranged recordings. Each column corresponds to the recording of one hammer stroke. Note high repeatability of the hammer signal.

D: First-arrival polarization analysis. Displayed is the incidence angle (from the horizontal) of seismic first arrival at SEIS.

E: Inclination of the HP³ mole measured by accelerometers in the mole.

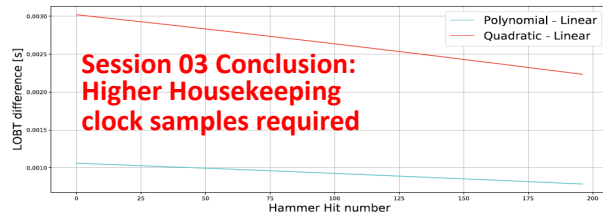
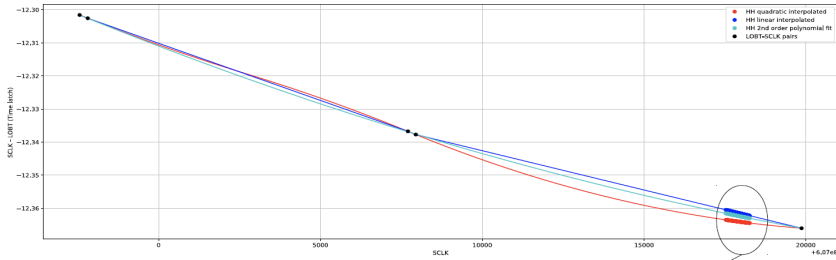


Signal Reconstruction: The HP³ mole produces seismic energy with a dominant frequency between around 100 and 150 Hz, above the nominal 50Hz Nyquist frequency of SEIS. During future hammering a compressed-sensing based method is then used to reconstruct the signal from fully aliased data.

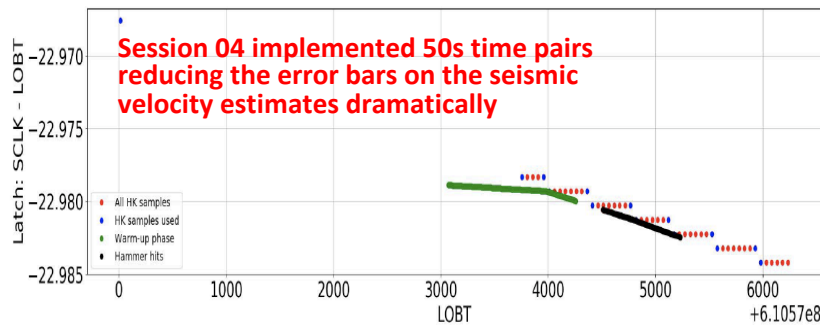
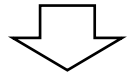


What we have learned so far

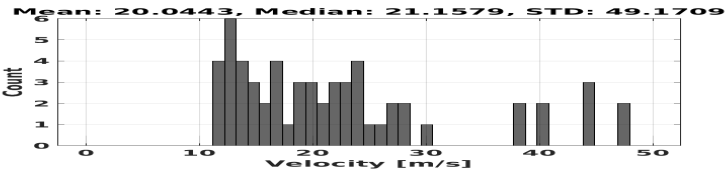
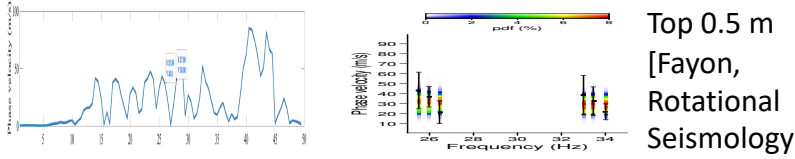
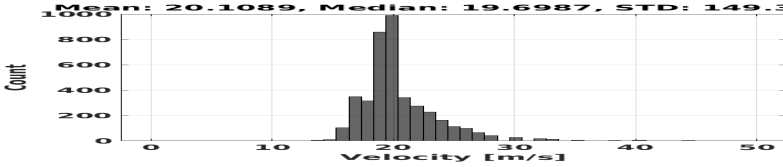
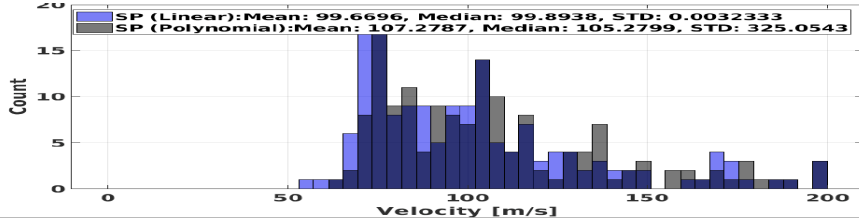
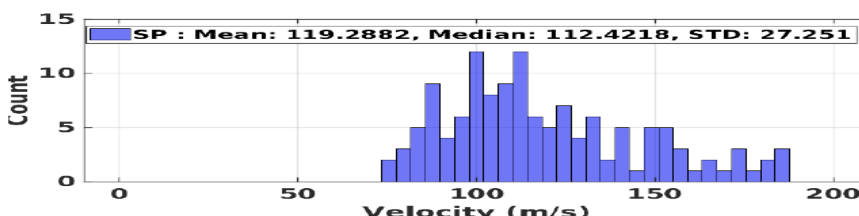
LOBT-SCLK Timing Correlation was key to constraining seismic velocities in the



Session 03 Conclusion:
Higher Housekeeping
clock samples required



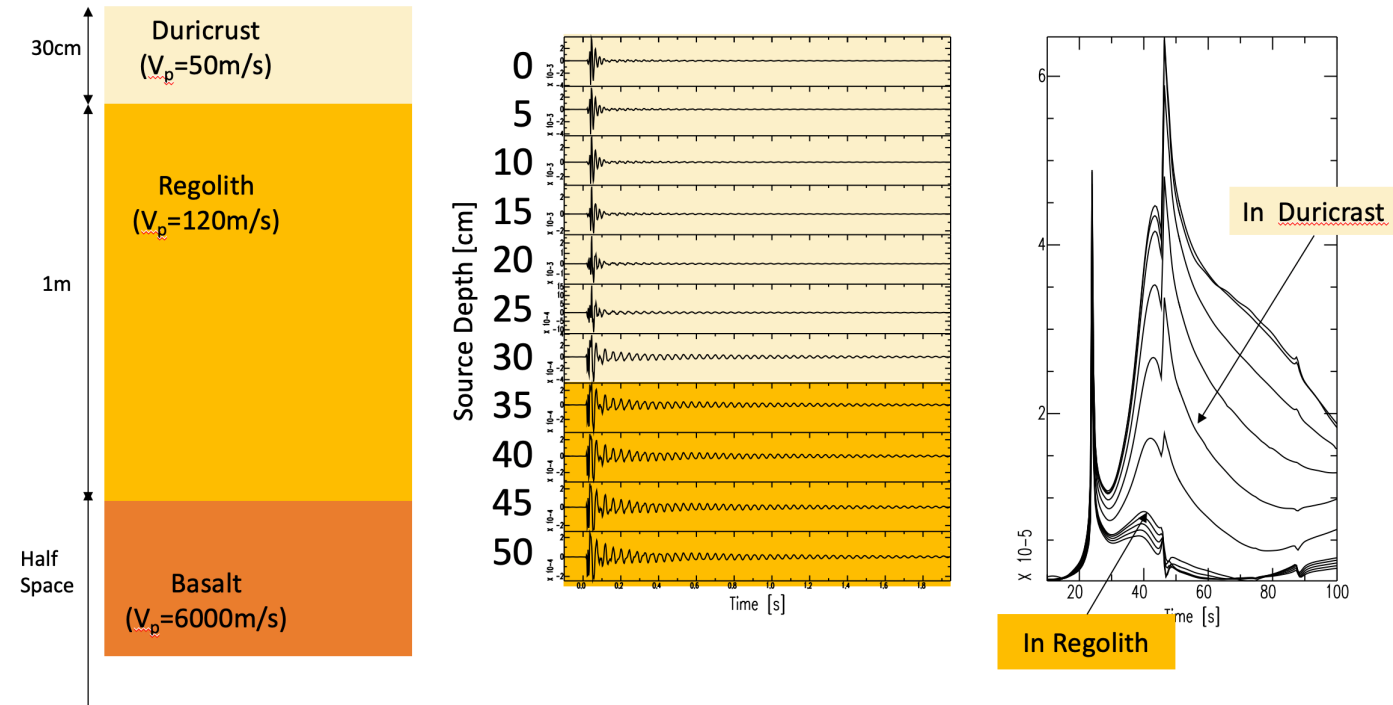
Session 04 implemented 50s time pairs
reducing the error bars on the seismic
velocity estimates dramatically

Session #	Velocity Estimate (m/s)	Comment	
01	V_p $\sim 20 \pm 50$		<ul style="list-style-type: none">Unknown trigger time biasLow velocities inconsistent with laboratory measurements [Delage]
	$(V_R < 50)$ $V_s = 36$		
02	V_p $\sim 20 \pm \gg 100$		FIR filter not uploaded
03	V_p $\sim 107 \pm \gg 100$		[ETH, with sparse LOBT-SCLK pairs]
04	V_p $\sim 119 \pm 27$		[ETH, with improved timing accuracy]

Conclusions and Path Forward

- Objective 1 met: Seismic Velocity estimate of 120m/s is firm and although low, is within the possible range of laboratory experiment;

- Objective 2 not met yet but:
 - Although a reflection from the bottom of regolith layer is not observed, regolith thickness can be inferred from analysis of the resonances in the regolith layer. Key parameters are Q , and reflection coefficient from basalt layer.



- Putting it all together: The Near Surface WG plans to compile all observations (Seismic Velocities, Geology, Radiation, Laboratory) into a single consistent physical model.